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EcoPassenger

Environmental Methodology and Data
Update 2016

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Introduction

Passenger mobility causes energy consumption, carbon dioxide emissions and other exhaust emissions. Travelers, as well as companies, want to know the ecological impact of trips according to the selected transport mode in order to minimize these impacts. For this purpose the International Union of Railways (UIC) supports the internet tool EcoPassenger since 2008. EcoPassenger is a tool to compare energy consumptions and global warming and local emissions of the different major transport modes on passenger traffic. The transport modes to be assessed are

- road transport
- rail transport
- air transport

The user is provided with information on individual routes. Thus the relevant environment related parameters of each transport process, such as route characteristics and length, load factor, vehicle size and engine type, are individually taken into account. Even it is possible to include the RFI (Radiation Forcing Index) of aviation into the calculation. The evaluation includes energy consumption, carbon dioxide emissions and exhaust emissions. The internet version of EcoPassenger as well as the integrated route planner have been realised by HaCon Hannover. The basic methodology for environment calculations was developed by ifeu in cooperation with the UIC. The main task of EcoPassenger is to deliver specific primary energy consumptions and pollutant emissions data for passenger trips in Europe and Russia.

1 System boundaries and basic definitions

1.1 Environmental Impacts

Transportation has various impacts on the environment. These have been mainly analysed by means of life cycle analysis (LCA). An extensive investigation of all kinds of environmental impacts has been outlined in [Borken 1999]. The following categories were determined:

- Resources consumption
- Land use
- Greenhouse effect
- Depletion of the ozone layer
- Acidification
- Eutrophication
- Eco-toxicity (toxic effects on ecosystems)
- Human toxicity (toxic effects on humans)
- Summer smog
- Noise

The passenger transport has impacts within all these categories. However, only for some of them is possible to perform a comparison of individual transports on a quantitative basis. In EcoPassenger therefore the selection of environmental performance values had to be limited to a reduced set of the most relevant parameters. The selection was done according to the following criteria:

- Particular relevance of the impact
- Proportional significance of passenger transport compared to overall impacts
- Data availability
- Methodological suitability for a quantitative comparison of individual journeys.

The following parameters for environmental impacts of transports were selected:

Table 1-1: Environmental impacts included in EcoPasssenger

Abbr.	Description	Reasons for inclusion
PEC*	Primary energy consumption	Main indicator for resource consumption
CO_2	Carbon dioxide emissions	Main indicator for greenhouse effect
NOx	Nitrogen oxide emissions	Acidification, eutrophication, eco-toxicity, human toxicity, summer smog
NMHC	Non-methane hydro carbons	Human toxicity, summer smog
PM	Exhaust particulate matter from vehicles (combustion), mainly PM 2.5 and from energy production and provision (combustion power plants, refineries, sea transport of primary energy carriers), composition: all particle sizes, about 80% PM 2.5, 90% PM 10 (by mass)	Human toxicity, summer smog

*PEC: Well-to-Wheels energy consumption, displayed as “liter petrol equivalent” (1 liter = 32.309 MJ, see appendix, Table 2-11)

Thus the categories land use, noise and depletion of the ozone layer were not taken into consideration. For electricity driven, rail transport the risks of nuclear power generation from radiation and waste disposal are also not considered.

Furthermore, the greenhouse gases methane and nitrous oxide are also not included in the current version. This is due to the fact that CO_2 is the dominant greenhouse gas in the transport sector. CO_{2eq}-emissions including the greenhouse effect of methane and nitrous oxide are, for conventional fuels, about 1 % higher than CO_2-emissions. The difference is higher for biofuels and electricity production, dependent on the mix of energy carriers (about 2 %-10 %). PM emissions are defined as exhaust emissions from combustion; therefore PM emissions from abrasion and twirling are not included so far.

Location of emission sources

Depending on the impact category, the location of the emission source can be highly significant. With regard to those emissions which contribute to the greenhouse effect, the location for land bound transport modes is not relevant, whereas flights in high distances have additional climatic impacts. Regarding eco-toxicity and human toxicity on the other hand, the location of the emission source is highly relevant:

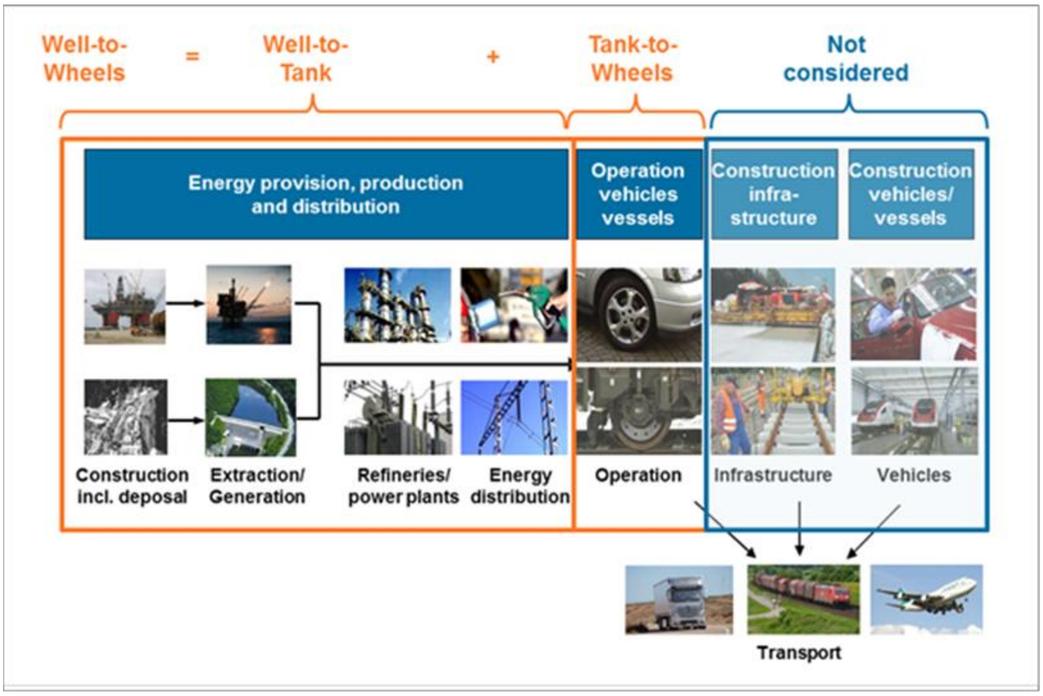
Particulate emissions from power plants and from engine combustion might have different impacts (due to different particle sizes and possibly also their composition) but it cannot be ruled out that they might also have the same impact. The knowledge about health effects is still uncertain and the data base given does not allow a further differentiation. Yet at least it can be ascertained that particulates resulting from combustion of diesel fuel have adverse health impacts.

System boundaries

In EcoPassenger, only those environmental impacts are considered which are linked to the operation of vehicles and to fuel production. Not included are therefore:

- the production and maintenance of vehicles
- the construction and maintenance of transport infrastructure
- additional resource consumptions such as administration buildings, stations, air-ports, etc..

All emissions directly caused by the operation of vehicles and the final energy consumption are taken into account. Additionally, all emissions and the energy consumption of the generation of final energy (fuels, electricity) are included. The following figure shows an overview of the system boundaries.



Source: own figure adapted from SBB, in: EcoTransIT Methodology Report
Figure 1-1: System boundaries of processes

1.2 Spatial differentiation

In EcoPassenger most of the European countries with railway lines are considered.

The environmental impacts of the different transport modes partly differ between the countries. Significant influencing factors are the types of vehicles used, and the type of energy carriers and conversion used. Wide differences result particularly from the method and national mix of electricity production.

Less pronounced are the differences in end energy consumption of similar vehicles in different countries. Thus in all countries usually passenger cars of different international manufacturers are used following the same registration approval rules. For air transport, the existing vehicles are likewise used internationally.

Bigger differences could instead exist for railway transport, where the various railway companies employ different railcars, locomotives and train configurations and buy energy from different sources. To include these differences, statistical data from the Railenergy project [UIC 2007] and updated energy values [UIC 2015] are used. This data are officially provided by the European railway companies via the International Union of Railways (UIC) based on the indicators and methodology of the Environmental Strategy Reporting System (ESRS) and the UIC Zero Carbon Project.

Thus the data are differentiated according to the following spatial criteria:

Country specific values: national mix of electricity production, load factors and specific energy consumption per train type (if available), the sulfur content of diesel fuel and the share of biofuels (if available).

Common data: emission factors and specific energy consumption for passenger cars, bus and air transport.

1.3 Transport modes and propulsion systems

Passenger transport in Europe is performed by different transport modes. Within the EcoPassenger the most important modes using common vehicle types and propulsion systems are considered. They are listed in the following table.

Table 1-2: Transport modes, vehicles and propulsion systems

Transport mode	Vehicles	Propulsion energy
Road	Passenger Cars	Gasoline, Diesel, LPG, Battery Electric
Rail	Rail transport with High-speed, Intercity, Regional and Suburban Trains	Electricity and diesel fuel
Aircraft transport	Air planes	Kerosene
Feeder	Busses, Metro, Taxis	Diesel, Electricity

For several relations ferries are part of the journey. In this version of EcoPassenger it was not possible to estimate the energy consumption and emissions for ferries because the timetable data of Merits (see the following section) did not allow identifying ferries as separate transport mode. Thus the distance for the ferry transport with train and car is considered, but no separate energy and emission values.

1.4 Routing

The aim of the integrated route planner is to find real routes for journeys in Europe based on existing train and flight connections and car routes for an ecological comparison of the different modes.

1.4.1 Data Base

The HAFAS route planner uses "Merits" train timetable data (UIC) and a database with European flight relations with up to two legs (www.flugplan.de).

1.4.2 Length of a Route

The length of the different routes is essential for the calculation of the different energy and emission values. Due to different emission data tables for different countries the route length of international journey has to be break down to single route lengths in different countries.

The length of the **car routes** in EcoPassenger is the result of an algorithm with linear distances and deviation factors.

Table 1-3: Estimated deviation factors and average speed of car routes

Linear distance	Deviation factor	Average speed
<=100 km	1.35	60 km/h
100 km - <=500 km	1.25	90 km/h
500 km - <=1000 km	1.15	100 km/h
>1000 km	1.1	110 km/h

If it is a cross border traffic the complete distance is divided in half and used for selecting the nation emission table, the one half for the start nation and the second half for the destination nation. The estimated average speed is needed for estimating the distribution of the estimated distance on to street classes (Motorway, Rural, Urban).

The length of **the train routes** is determined by the polygon defined by all in-between stops of a train. The length of the train route between two connected stations is calculated by the line of sight distance which is extended by 20%-30% depending on cases. The advantage of this EcoPassenger methodology compared to "default" pure rail net-work routing comes from the use of timetable data for the routing calculation, the real routes used for passenger travels can differ from the default geographical shortest route, and it varies on different kind of train services.

Every country has an own table concerning emission data of cars and trains. Every section of an international journey is assigned to a certain country by flags in the routing data or UIC codes of passed by stations. If a train route contains explicitly a border stop, the route is divided at this border. If there is no border stop but the UIC code of two consecutive stops changes, the route section between these stops is simply cut into halves and every half is assigned two one of the both countries.

The emissions of a train depend on the type of traction. The system holds the data, if a station can only be reached by diesel trains. This data is extracted from the EcoTransit system, which has collected this data for the whole railway network in Europe [EcoTransIT 2014]. If a train passes a station which can only be reached by Diesel traction it is presumed, that the whole train runs with diesel traction. Otherwise electric traction is assumed.

Ferries do not have a special treatment because of a lack of reliable emission data. They will be handled as a car or train route instead based on the distance of the different harbors.

Flights are calculated with the air-line distance. For deviations from the air-line distance, depending from air routes or wait loops an average distance of 50 km is added. A flight journey needs public transport or private car to reach the airports. The length of the route is estimated by the "line of sight" for public transport added by 30% or the result of car routing component for the use of the car. The country of the airports locations defines which country emission data table is used for the whole airport transfer. For distances over 100 km IC trains are assumed, for less than 100 km regional trains.

The search for flights considers all airports in a radius of 250 km of the journey origin and destination. If several flight connections are possible the system searches for the shortest route and values the length of the airport transfer twice for the selection of shortest route.

The EcoPassenger system has no access to flight timetable data for an online routing. But the possible flight relations (including 1-stop flights) are determined based on real flight data. A flight relation between two airports was added to the system, if there is at least one flight per week available. The system considers all direct flight connections and 1-stop flight connections, if the total flight distance does not exceed the line of sight distance between start and destination by 100%.

The travel times for flight journeys are estimated with average values for the travel times between the airports and the average travel times for the feeder. Feeder times are estimated with an average speed of 70 km/h for feeder distances below 100 km and 100 km/h for longer distances. For the transfer on the airports 75 minutes are added in total.

2 Energy and emission data

2.1 Energy supply (Well-to-Tank)

The main energy carriers used in passenger transport are gasoline, diesel, LPG and electricity. To compare the environmental impacts of transport processes with different energy carriers, the total energy chain has to be considered:

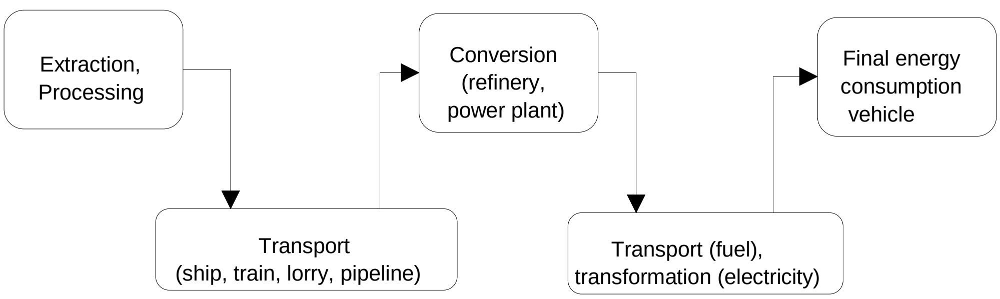
Energy chain of electricity production:

- Exploration and extraction of the primary energy carrier (coal, oil, gas, nuclear etc.) and transport to the entrance of the power plant.
- Conversion within the power plant (including construction and deposal of power stations).
- Energy distribution (transforming and cable losses).

Energy chain of fuel production:

- Exploration and extraction of primary energy (crude oil, gas) and transport to the entrance of the refinery.
- Conversion within the refinery (including construction and deposal of refineries).
- Energy distribution (transport to petrol station, filling losses).

Figure 2-1: Energy chain for fuel and electricity



For each process step, energy is required. The energy consumption over the total energy chain depends on the efficiency of the individual steps of the chain, which differs for each production path.

2.1.1 Exploration, extraction, transport and production of fuels

Emission factors and energy demand for the construction and disposal of refineries, exploration and preparation of different input fuels; the transport to the refineries; the conversion in the refinery and transport to the filling station are taken from TREMOD [ifeu/INFRAS/LBST 2015] and EN 16258 [CEN 2012], both based on the European JEC-studies [JEC 2014].

Biofuels are considered for Petrol (Ethanol) and Diesel (Biodiesel). The emission values for biofluel are based on ifeu studies [ifeu 2014]. For EcoPassenger it was not possible to research for country specific use of Biofuels. The assumptions made for EcoPassenger are shown in the appendix.

The following table shows the specific figures for the emissions and the energy consumption for the Well-to-Tank-emissions.

Table 2-1: Emission factors and energy efficiency of fossil fuels for energy production and delivery (Well-to-Tank]

	Efficiency*	CO_2	NO_x	NMVOC	PM
		kg/kg	g/kg	g/kg	g/kg
Gasoline*	85%	0.46	1.7	2.1	0.07
Diesel*	82%	0.48	1.8	1.5	0.08
Kerosene	83%	0.63	1.7	1.5	0.06
LPG	84%	0.62	2.0	1.5	0.05

*including biofuels
Efficiency: Relation final energy/primary energy; emission factors related to final energy
Source: [ifeu 2014],[ifeu/INFRAS/LBST 2015], [CEN 2012]

In EcoPassenger the total Well-to-Wheels-emissions (sum of Well-to-Tank and Tank-to Wheels) are used (see Figure 1-1). The Tank-to-Wheels emission factors for CO_2 are shown in the appendix, Table 2-12. For NO_X, NMVOC, PM the Tank-to-Wheels emissions depend from the vehicle concept and transport mode (see Table 2-8 and Table 2-9).

2.1.2 Electricity production

The emission factors of electricity production depend mainly on the mix of energy carriers and the efficiency of the production. The reference for the energy mix is the national production mix of each country.

The values for the Energy mix of the electricity production are taken from Eurostat [Eurostat 2015] or IEA [IEA 2015]. Table 2-2 shows the input values for the electricity mix.

The efficiency and emission factors for the countries used in Ecopassenger are calculated with the electricity grid model by ifeu [ifeu 2016]. The model delivers average emission factors for the electricity production in 2013 per country related to the substation. For values related to the pantograph of electric trains the losses from substation to pantograph were added, based on values from UIC [UIC 2016]. Table 2-3 shows the resulting values.

Table 2-2: Energy split of electricity consumption in 2013

	Country	Source	Hard Coal	Brown Coal	Fuel Oil	Gas	Nuclear	Renewable
AT	Austria	EUROSTAT	6.5%	0.0%	1.1%	13.3%	0.0%	79.2%
BA	Bosnia and Herzegovina	IEA	0.0%	56.6%	0.2%	0.2%	0.0%	43.0%
BE	Belgium	EUROSTAT	3.7%	0.0%	0.2%	28.3%	51.7%	16.1%
BG	Bulgaria	EUROSTAT	4.4%	38.4%	0.5%	5.2%	34.1%	17.5%
CH	Switzerland	IEA	0.0%	0.0%	0.1%	1.1%	36.7%	62.1%
CZ	Czech Republic	EUROSTAT	6.0%	41.6%	0.1%	4.9%	36.3%	11.2%
DE	Germany	EUROSTAT	19.2%	25.3%	1.1%	12.5%	15.6%	26.2%
DK	Denmark	EUROSTAT	40.1%	0.0%	1.0%	9.5%	0.0%	49.3%
EE	Estonia	EUROSTAT	85.6%	0.5%	1.0%	2.8%	0.0%	10.1%
EL	Greece	EUROSTAT	0.0%	44.9%	9.2%	18.5%	0.0%	27.4%
ES	Spain	EUROSTAT	14.5%	0.0%	4.9%	20.7%	20.1%	39.8%
FI	Finland	EUROSTAT	14.9%	4.4%	0.3%	10.2%	33.3%	36.9%
FR	France	EUROSTAT	3.8%	0.0%	0.4%	3.5%	74.4%	17.9%
HR	Croatia	EUROSTAT	17.2%	0.1%	1.6%	14.5%	0.0%	66.5%
HU	Hungary	EUROSTAT	0.2%	20.3%	0.2%	18.2%	51.6%	9.6%
IE	Ireland	EUROSTAT	18.4%	9.4%	0.8%	48.7%	0.0%	22.8%
IT	Italy	EUROSTAT	15.5%	0.0%	5.3%	38.6%	0.0%	40.5%
LT	Lithuania	EUROSTAT	0.0%	0.0%	5.0%	54.2%	0.0%	40.8%
LU	Luxembourg	EUROSTAT	0.0%	0.0%	0.0%	76.7%	0.0%	23.3%
LV	Latvia	EUROSTAT	0.0%	0.0%	0.0%	41.2%	0.0%	58.7%
ME	Montenegro	EUROSTAT	0.0%	34.4%	0.0%	0.0%	0.0%	65.6%
NL	Netherlands	EUROSTAT	24.4%	0.0%	1.2%	57.5%	2.8%	14.0%
NO	Norway	EUROSTAT	0.0%	0.0%	0.0%	1.9%	0.0%	98.0%
PL	Poland	EUROSTAT	49.5%	34.1%	1.1%	4.4%	0.0%	10.9%
PT	Portugal	EUROSTAT	23.0%	0.0%	3.3%	14.0%	0.0%	59.6%
RO	Romania	EUROSTAT	0.6%	26.6%	0.9%	14.9%	19.8%	37.1%
RS	Serbia	EUROSTAT	0.0%	71.3%	0.0%	0.8%	0.0%	27.8%
RU	Russian Federation	IEA	8.8%	5.9%	0.8%	49.9%	16.3%	18.3%
SE	Sweden	EUROSTAT	0.4%	0.2%	0.3%	0.8%	42.6%	55.7%
SI	Slovenia	EUROSTAT	2.4%	26.7%	0.0%	3.0%	34.0%	33.8%
SK	Slovakia	EUROSTAT	3.9%	7.5%	1.6%	10.5%	54.5%	21.9%
TR	Turkey	EUROSTAT	13.1%	12.5%	0.7%	44.1%	0,0%	29.7%
UK	United Kingdom	EUROSTAT	36.9%	0.0%	0.6%	27.3%	19.0%	16.3%

Source: : IEA 2015, Eurostat 2015

Table 2-3: Energy efficiency and emission factors of the electricity supply for railway transport in European countries

	Counry	Efficiency	CO_2	NO_X	NMVOC	PM
			kg/kWh	g/kWh	g/kWh	g/kWh
AT	Austria	63%	0.18	0.32	0.02	0.05
BA	Bosnia and Herzegovina	29%	1.17	0.89	0.02	0.29
BE	Belgium	34%	0.22	0.43	0.02	0.07
BG	Bulgaria	24%	0.87	0.93	0.03	0.26
CH	Switzerland	47%	0.01	0.06	0.01	0.02
CZ	Czech Republic	28%	0.77	0.89	0.03	0.19
DE	Germany	36%	0.65	0.88	0.04	0.10
DK	Denmark	45%	0.48	1.48	0.04	0.13
EE	Estonia	27%	1.38	1.18	0.03	0.35
EL	Greece	34%	0.88	0.83	0.05	0.16
ES	Spain	40%	0.34	0.85	0.04	0.12
FI	Finland	37%	0.29	0.85	0.03	0.08
FR	France	29%	0.09	0.28	0.01	0.06
HR	Croatia	46%	0.36	1.10	0.03	0.11
HU	Hungary	25%	0.48	0.65	0.03	0.11
IE	Ireland	43%	0.57	0.98	0.03	0.07
IT	Italy	37%	0.51	1.27	0.07	0.11
LT	Lithuania	29%	0.53	1.18	0.09	0.09
LU	Luxembourg	43%	0.42	0.58	0.04	0.05
LV	Latvia	43%	0.29	0.72	0.05	0.05
ME	Montenegro	42%	0.59	0.45	0.01	0.15
NL	Netherlands	44%	0.57	0.92	0.04	0.11
NO	Norway	81%	0.01	0.02	0.00	0.01
PL	Poland	31%	1.09	2.26	0.04	0.42
PT	Portugal	44%	0.42	1.32	0.05	0.11
RO	Romania	33%	0.58	0.58	0.03	0.14
RS	Serbia	30%	1.18	0.90	0.02	0.29
RU	Russian Federation	25%	0.76	1.49	0.09	0.18
SE	Sweden	40%	0.03	0.19	0.01	0.03
SI	Slovenia	36%	0.43	0.39	0.01	0.10
SK	Slovakia	32%	0.28	0.52	0.02	0.09
TR	Turkey	33%	0.75	1.06	0.07	0.10
UK	United Kingdom	34%	0.60	1.55	1.55	0.16

Source: IEA 2015, Eurostat 2015, ifeu 2016

For CO_2-emissions an additional value can be selected: The "railway mix including green cerificates". For more information about these values see UIC Zero Carbon Footprint Report [UIC 2014].

2.2 Transport modes

2.2.1 Passenger car

For the journey with passenger cars different vehicle types were defined.

Table 2-4 Characterization of passenger cars

Emission Standard	Energy	Size (Euro Market Segment)	Load Factor
Conventional Euro-1-6	Gasoline Diesel LPG Battery Electric	Compact class (A, B) Medium sized class (C, small M) Luxury class (D-J)	Average (1.5 persons) Variation from 1-5 persons

Energy consumption and emissions of passenger cars are different for each road category (highway, rural, urban). The urban emission factors include the extra emissions for cold start and evaporation. Values for EcoPassenger were estimated with the COPERT 4 model, version 11.3 [Emisia 2015], HBEFA 3.2 [INFRAS 2014] and TREMOD [ifeu 2014]. All tools use energy and emission data from "Real world" driving cycles, not from the legislative NEDC-driving cycle. The following values are used:

- HBEFA: Emission factors for NOx, NMHC and PM for petrol and diesel cars
- Copert: emission factors and energy consumption for LPG cars
- TREMOD: energy consumption for petrol, diesel and electric cars per market segment[1]

Country specific parameters could not be included, because they are hardly available. So assumptions are made for all parameter with influence on the energy and emission values of passenger cars. The resulting values for fuel consumption are listed in the following table.

Table 2-5 Average fuel consumption of Euro-5 passenger cars

	Diesel (l/100 km)			Petrol (l/100 km)		
	small	medium	large	small	medium	large
Motorway	4.5	5.3	6.7	6.3	7.5	9.2
Rural	3.8	4.5	5.8	4.9	5.8	7.2
Urban	5.7	6.7	8.4	7.3	8.7	10.5

Source: TREMOD

[1] HBEFA and Copert so far use engine capacity as differentiator between size classes; whereas TREMOD changed to market segments in 2014

2.2.2 Railways

The railway transport is differentiated according the system used in the UIC CO_2 and Energy Database [UIC 2016] (see the following table).

Table 2-6: Characterization of passenger trains

Transport Service	Traction Class
High-speed	Electric
Intercity	Electric, Diesel
Regional/Urban	Electric, Diesel

The specific energy consumption values for EcoPassenger are derived from the UIC CO_2 and Energy Database (ESRS) for the year 2014 [UIC 2016].

A specific value per passenger-km for different train service types has been used for seven countries: Belgium, Switzerland, Czech Republic, Germany, Spain, Finland and Russian Federation. For 13 countries average values over all service types are available (Austria, Bulgaria, Denmark, France, Croatia, Hungary, Ireland, Italy, Lithuania, Netherlands, Romania, Sweden, Slovenia). For all other countries, the average values of the railway companies supporting the Environment Strategy Reporting System (ESRS) are used. For the model feature “maximum load factor” the specific energy values per seat-km (load factor=100%) are used. If the value for load factor is not available, a default value of 35% is used.

The following table summarizes the average values. The specific values per passenger-km for single train types in each country are property of UIC database.

Table 2-7: Average values for specific energy consumption of European trains

	Electric (Wh/Pkm)	Diesel (g/Pkm)
Specific energy consumption per passenger-km	88.2	25.2
	Electric (Wh/seat-km)	**Diesel (g/seat-km)**
Specific energy consumption per seat-km	30.9	8.8

Source: Data elaboration from UIC 2016 countries database

Emission factors for diesel engines

Emission factors for diesel engines are taken from the Rail Diesel Project [UIC 2006] and the UmweltMobilCheck [DB 2015]. An average emission factor for railcars and main locomotives has been estimated by RailDiesel with most representative engines of railway companies. For DB AG average values for Intercity and regional trains are available. For the update of EcoPassenger (EP 2015) the older values of RailDiesel are updated by estimation based on the development on DB values and the legislation. It is assumed that the NOx-value is 20% and the PM-value 30% better than five years ago (EP 2010).

Table 2-8: Tank-to-Wheels emission factors for diesel engines (in g/kg Diesel)

Transport service	NOx	NMVOC	PM*
Average values Rail Diesel Project			
Railcars	40.0		1.0
Main Locomotives	64.7		1.15
DB AG 2015			
Intercity	49.3	1.9	0.5
Regional/suburban	38.1	1.6	0.6
EP 2010	52.3	2,6	1.1
EP 2016	41.8	2.6	0.77

Remarks: *PM from combustion; EP: EcoPassenger
Source: Rail Diesel project [UIC 2005]; UmweltMobilCheck [DB 2015], ifeu assumptions

2.2.3 Air traffic

For air transport the methodology of TREMOD [ifeu 2011], [ifeu 2014] is used. TREMOD calculates energy and emissions of a flight dependent on flight phase, flight distance and aircraft type. Energy and emission factors come from the EMEP-EEA Guidebook [EMEP-EEA 2013].

2.2.3.1 Flight phases

A flight is divided in different flight phases:

- LTO (Taxi out, Take-off, climb out. Approach landing Taxi in, height <3000 ft)
- CCD (Climb, Cruise, descent, height>3000 ft)

2.2.3.2 Energy consumption and emission factors

The energy and emission data are taken from [EMEP-EEA2013], which includes energy and emission values for the flight phases and different distance classes for the most important airplane types. To estimate average emission factors the average feet mixture of flights for each distance class starting from German airports was used, which should be similar to other European countries. Typical airplanes types for short and medium distance flights within Europe are the B737-family and A319-321-family.

The following table shows the resulting values for the energy consumption:

Table 2-9: Tank-to-Wheels energy consumption and emission factorsof air traffic for all distance classes used in EcoPassenger

Distance class	Energy consumption (g kerosene/seat-km)	NOx (g/kg*)	NMHC (g/kg*)	PM (g/kg*)
125 km	120.5	12.6	0.95	0.24
250 km	75.7	14.2	0.72	0.27
375 km	60.1	13.8	0.72	0.26
500 km	42.7	16.6	0.52	0.29
625 km	38.4	15.1	0.58	0.29
750 km	36.0	14.7	0.59	0.30
1000 km	33.2	14.2	0.51	0.30
>1000 km	19.0	14.4	0.45	0.31

*Emissions in gram per kg kerosene
Source: EMEP-EEA-Guidebook 2013, ifeu-assumptions

2.2.3.3 RFI factor

The climatic impacts of the different pollutants can be converted to those of carbon dioxide. This is done using the “Radiative Forcing Index” (RFI, see [IPCC 1999] and short description in [ATMOSFAIR 2008]). The RFI Factor takes into account the climate effects of other GHG emissions (in particular nitrogen oxides, ozone, water, soot, sulphur), especially for emissions in high altitudes. The result is a quantity of CO_2 that would have to be emitted to cause the same warming effect, when averaged globally, as the various pollutants together.

Air traffic causes an additional global warming in altitudes above 9 kilometres. These are usually reached in the cruise phase of flight distances of greater than approx. 400–500 km [ATMOSFAIR 2008]. Therefore in EcoPassenger the RFI factor is included as an option for flights with distances over 500 km. The following assumptions are made:

- Distance class 500 km: 50% of all flights reach critical altitudes
- Distance class 625 km: 75% of all flights reach critical altitude
- Distance class 750 km and more: all flights with critical altitudes (100% RFI)
- Only the distance travelled during cruise is critical.

For cruise in critical altitudes a RFI factor of 3 is used (this means that the direct CO_2 emissions of cruise are multiplied by 3). This value is also used by ATMOSFAIR.

With these assumptions the following average RFI factors dependent from flight distance are used in EcoPassenger:

Table 2-10: Average RFI factors for different distance classes

Distance class (km)	Average RFI factor
500 km	1.27
625 km	1.47
750 km	1.6
1000 km	1.87
>1000 km	2.5

Source: ATMOSFAIR 2008, IPCC 1999, ifeu-assumptions

2.2.3.4 Load factors

The load factor for passenger flights within the EU ranges from 71% (national traffic) to 80% (international traffic) [DESTATIS 2015], [EUROSTAT 2015]. From this we estimate an average load factor of 71% (Distance classes 125-375 km), 75% (Distance classes 500 and 625 km) and 80% (distance classes from 750 km and higher).

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Appendix: Description of important data sources

COPERT 4 (Emisia, EEA)

Copert 4 is a software program which is developed as a European tool for the calculation of emissions from the road transport sector. The emissions calculated include regulated (CO, NOx, VOC, PM) and unregulated pollutants (N2O, NH3, SO2, NMVOC speciation) and fuel consumption is also computed.

Copert 4 was funded by the EEA and is used in different European countries and in the EU. The recent data set of emission factors was developed by a European research project called ARTEMIS which is based on a broad set of emission measurements and methodologies developed by leading European scientists in the field of transport emissions. In EcoPassenger the Version 11.3 from 2015 is used [Emisia 2015].

Electricity grid model (ifeu)

The UMBERTO based "master network" for the modelling of grid power has been maintained since 2001. This network, made up of basic power plant types and raw material upstream processes, allows for a flexible approach to all types of network composition, be it national networks, group based or other special scenarios (future or marginal mixes). The parameterisation is done through a percentage adjustment of the energy mix, information about the raw material origin as well as setting a number of technical factors (efficiency, exhaust gas treatment, etc.).

This model is used regularly to calculate the electricity mix of European and non-European countries that are covered by the EUROSTAT and the International Energy Agency (IEA) data service. In addition it is used to determine regional mixes (e.g. EU28 or UCTE). Updates are done yearly for European countries and every two years for other countries. The 2013 update was partly funded by EWI for the update of EcoTransIT World and UIC for the update of EcoPassenger [ifeu 2016].

Railenergy (UIC, EU)

Railenergy is an Integrated Project co-funded by the European Commission under the 6th Framework Programme for Research and Development. The full name of the project is "Innovative Integrated Energy Efficiency Solutions for Railway Rolling Stock, Rail Infrastructure and Train Operation" [UIC 2007].

The overall objective of Railenergy is to cut the energy consumption by developing a holistic framework approach, new concepts and integrated technical and technological solutions to improve energy efficiency. The holistic approach is at the heart of the project, creating the spirit for the proper integration and synergies of the combined results.

Railenergy will address the problem of energy efficiency within an optimised railway system thus contributing to a reduction in the life cycle costs of railway operation and of CO_2 emissions per seat-kilometre or tonne-kilometre. The project target is to achieve a 6% reduction in the specific energy consumption of the rail system by 2020, assuming that traffic volumes double in comparison with current figures.

Rail Diesel Project (UIC, EU)

As cornerstone of the "UIC Diesel Action Plan" a one-year "Rail Diesel Study", co-funded by the European Commission, was performed in 2005 [UIC 2005].

Partners of the UIC for this study have been the Community of European Railways (CER), the Union of European Railway Industries (UNIFE), the European Association of Internal Combustion Engine Manufacturers (Euromot) and AEA Technology as external consultant.

EMEP EEA Emission Inventory Guidebook – 2013 (EEA)

The Guidebook has been prepared by the Convention's Task Force on Emission Inventories and Projections (TFEIP), with detailed work by the Task Force's expert panels and the European Environment Agency (EEA). The present edition of the Guidebook replaces all earlier versions. The Guidebook is compatible with, and complementary to, the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Its intention is to support reporting under the UNECE Convention on Long-Range Transboundary Air Pollution and the EU directive on national emission ceilings [EMEP_EEA 2013].

HBEFA (INFRAS)

The Handbook of Emission Factors for Road Transport (HBEFA) was originally developed on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria. In the meantime, further countries (Sweden, Norway, France) as well as the JRC (European Research Center of the European Commission) are supporting HBEFA [INFRAS 2014].

The Handbook Emission Factors for Road Transport (HBEFA) provides emission factors for all current vehicle categories (PC, LDV, HGV, urban buses, coaches and motor cycles), each divided into different categories, for a wide variety of traffic situations. Emission factors for all regulated and the most important non-regulated pollutants as well as fuel consumption and CO_2 are included. The newest version HBEFA 3.2 dates from July 2014. HBEFA 3.2 is a follow up of the ARTEMIS road model. Therefore HBEFA and Copert use the same database.

TREMOD (UBA, ifeu)

TREMOD (Transport emission model) is carried out by IFEU on behalf of the German Federal Environmental Agency since January 1993. Scope of the TREMOD is the analysis of motorised transport in Germany , i.e. its mileage, energy use and emissions. TREMOD is available as an updated version 5.5 since November 2014 [ifeu 2014]. Due to its volume and complexness, TREMOD is not available to the public.

TREMOD is currently used by the following institutions: German Federal Environmental Agency, Federal Highway Research Institute and several federal ministries, Association of the German Automotive Industry VDA (since 1996) and Deutsche Bahn AG (since 1997). These partners conceptually and financially support the enhancement of the model and its continuous updating to state-of-the-art scientific knowledge as well as new legislation and technology.

In the road transport sector, TREMOD is harmonised with the Handbook Emission Factors for Road Transport (HBEFA). This means that the emission factors of HBEFA are used in TREMOD calculations.

Appendix: Conversion Factors

Table 2-11: Density and energy content of fuels

	Density	Energy Content	
Gasoline fossil	0.742 kg/l	43.543 MJ/kg	32.309 MJ/l
Bioethanol	0.79 kg/l	26.658 MJ/kg	21.060 MJ/l
Diesel fossil	0.832 kg/l	42.960 MJ/kg	35.743 MJ/l
Biodiesel	0.879 kg/l	37.242 MJ/kg	32.736 MJ/l
LPG	0.600 kg/l	45.969 MJ/kg	27.581 MJ/l
Kerosene	0.800 kg/l	42.800 MJ/kg	34.240 MJ/l

Source: Arbeitsgemeinschaft Energiebilanzen: www.ag-energiebilanzen.de, ifeu assumptions

Table 2-12: CO_2-emission factors of fuels

	CO_2 WtT g/kg	CO_2 TtW g/kg	CO_2 WtW g/kg
Gasoline fossil	0.57	3.14	3.71
Bioethanol	-1.18	1.94	0.76
Gasoline *	0.45	3.06	3.51
Diesel fossil	0.63	3.18	3.81
Biodiesel	-1.80	2.64	0.84
Diesel **	0.48	3.14	3.62
Kerosene	0.63	3.15	3.78

*Share Bioethanol (related to energy content): 4,1%
**share Biodiesel (related to energy content): 5,5%
WtT=Well-to-Tank, TtW=Tank-to-Wheels, WtW=Wells-to-Wheels
Source: TREMOD, ifeu assumptions